Cracking and Mechanical Properties of Airport Concrete Pavement with Fiber and Expansive Agent

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Abstract: Polypropylene fiber and expansive agent are used in airport concrete to improve its shrinkage cracking resistance and mechanical properties. The concrete specimens with amount content of polypropylene fiber or expansive agent or both of them are prepared. The morphology of specimens is observed by scanning electron microscope, the time when the first crack occurred is recorded through slap test, and the mechanical properties such as compressive strength and impact energies of concrete are measured. The results show that polypropylene fiber in concrete can reduce the shrinkage and delay the first crack, improve the impact resistance obviously, and improve the compressive strength slightly. Expansive agent can compensate the shrinkage and reduce cracks of concrete pavement markedly, and improve the mechanical properties of concrete pavement slightly. The study provides recommendations for cracking control of airport concrete pavement in the future.

Key words: concrete pavement; polypropylene fiber; expansive agent; crack; mechanical performance

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1 Introduction

Having the advantages of high strength and stiffness, good stability and durability, simple curing process, as well as low construction cost compared to asphalt pavement, the concrete pavement has been the main type of airport runway. However, the great shrinkage crack and high brittleness of the cement concrete are major problems in the design and construction of concrete pavement, and there are many joints on the pavement [1-2]. Under the influences of rainwater and external loads, the joints are always damaged, thus leading to faulting and transverse cracks. As the runways are exposed to freeze-thaw cycles, rain, snow, and dynamic load of airplanes for long, they may gradually lose surface functional properties, and suffer structural deterioration or damage, thus leading to fatal crash [3-4].

To solve the problems mentioned above, the fibers such as glass, polypropylene, and nylon fibers etc. are added to reduce the crevices of concrete [5-6]. Due to its high strength, high modulus of elasticity, good acid and alkali resistance, polypropylene fiber is a vital component of high-performance concrete and used as a modifier in concrete pavement now. Introduced into concrete in an appropriate proportion, it may decrease shrinkage crack and improve the toughness of concrete pavement, which has good foreground in airport engineering application [7-8].

Expansive agents are widely used to compensate and reduce the thermal shrinkage of concrete which include calcium oxide (CaO), magnesium oxide (MgO) and ettringite (AFt) type. This approach is first used in the Baishan Dam of China in the 1970s[9-10]. The main phases of the MgO-

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type expansive agent are CaO and MgO. CaO reacts to water and forms $Ca(OH)_2$ which causes an expansion to compensate the shrinkage of concrete in early age. Likewisely, $Mg(OH)_2$ from MgO causes a delayed expansion to compensate the shrinkage of concrete in later age[11]. Compensation of the thermal shrinkage with MgO-type expansive agents may be an effective and economical method for preventing the concrete from thermal cracking.

Shrinkage may cause cracking in concrete with the consequent increase on the permeability and risk of environmental agents penetrating to the exposed surfaces. Thus, the durability and serviceability of concrete structures can be impaired and the service life is reduced[12]. It is very important to use polypropylene fiber and expansive agent to reduce the shrinkage cracks and improve the properties of concrete pavement in airport.

2 Materials and Methods

2.1 Materials

Expansive agent (EA) is prepared from magnesite and dolomite calcined in an electric furnace in laboratory at 1 050—1 200 °C for 1 h, then allowed to cool down in air and ground to powder. The 42.5 MPa Portland cement and Grade I fly ash are used, and the chemical compositions of them are shown in Table 1. The aggregate (grain diameter 5—20 mm) and sand from Nanjing are not alkaline. The superplasticizer is a retarding naphthalene water reducing agent. The polypropylene fiber from Jiangsu Province used in the test is filamentous, and its physical mechanical properties are presented in Table 2.

2.2 Testing methods

The plastic shrinkage cracking tests on slabs are conducted in the paper. The mix proportions of concrete are shown in Table 3, and the sizes of slab mould for the tests are shown in Fig. 1.

Table 1 Chemical composition of materials %

Item	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L. O. I	Sum
Cement	23.53	3.91	5.08	58.03	4.37	2.50	2.31	99.73
Fly ash	46.53	27.69	16.52	2.56	1.45	0.80	3.82	98.57
EA	6.36	0.90	1.24	40.06	49.10		1.32	99.42

Table 2 Physical and mechanical properties of polypropylene fiber

Diameter / μm	Length/ mm	Tensile strength / MPa	Elastic modulus/ GPa	Ultimate elongation / %	Density/ (g • cm^{-3})	Melting point/ ℃	Acid solubility/ %	Alkaline solubility/ %
45	15	410	3.85	28	0.91	160—170	0.3	0.3

Table 3 Mix proportion of concrete kg • m^{-3}

Item	Cement	Fly ash	Water	Coarse aggregate	Sand	Superplasticizer	Fiber	Expansive agent
1	300	35	120	1 450	560	6.03	0	0
2	300	35	120	1 450	560	6.03	1.34	0
3	300	35	120	1 450	560	6.03	2.68	0
4	300	35	120	1 450	560	6.03	2.68	20.1

The cracking resistance performance of plain concrete and concretes with different content of polypropylene fiber are studied. The following parameters are recorded, i.e., the time when the first crack occurs, the total number of cracks, and the length and width of cracks. When the casting is completed, the recordation is performed once an hour until 24 h. Then the data are recorded twice a day (at 9 a.m. and 4 p.m.) for 7 days, and the total crack area per unit area are calculated[13-14].

The concrete specimens used for compressive strength test are 100 mm×100 mm×100 mm and tested according to Chinese standard JTJ053—94. The concrete specimens used for impact test are ∅152 mm × 63.5 mm and tested according to drop-weight method recommended by American Concrete Institute Committee 554; the impact resistance of concrete can be indicated by the following three indexes: the impact times N_1 until

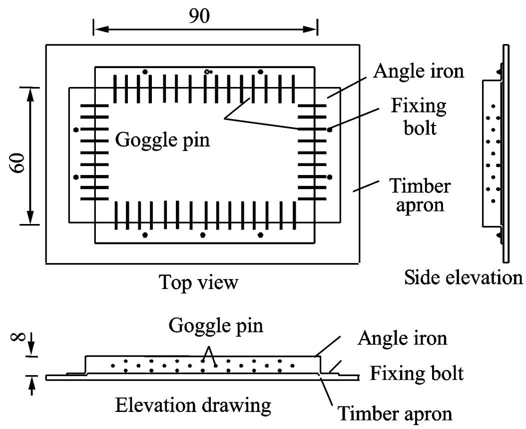

Fig. 1 Mould structure for slab test

the first crack happens, the impact times N until the concrete damages and impact toughness W.

The mix proportion of paste is similar to that of Item 4 in Table 3, but no sand and coarse aggregate. The paste is cured in water for 28 days, and placed in absolute alcohol to stop its hydration, then dried in an oven with 60 ℃ temperature for 48 h before scanning electron microscope (SEM) observation. The morphologies of paste are observed by SEM.

3 Results and Discussion

3.1 Effect of polypropylene fiber on concrete cracking

The results of the first cracks time and total crack area per unit area in concrete are presented in Figs. 2,3.

When the content of polypropylene fiber is 2.68 kg/m^3 (Item 3 in Table 3), the time when the first crack occurs is 45 min and 137 min later than that of the concrete samples with 1.34 kg/m^3 polypropylene fiber (Item 2) and that of plain concrete (Item 1), respectively. Compared with the concrete samples with 1.34 kg/m^3 polypropylene fiber and plain concrete, the total crack area per area is reduced by 44.3% and 62.2% respectively, and cracking resistance reaches Grade II.

When the content of polypropylene fiber is 2.68 kg/m^3 and 20.1 kg/m^3 expansive agent (Item 4 in Table 3), the first crack occurs after 8 h, which is 105 min later than that of the concrete samples with 2.68 kg/m^3 polypropylene fiber (Item 3). The crack area per area is reduced by 43.1% and 78.2% compared with the concrete samples with 2.68 kg/m^3 polypropylene fiber (Item 3) and plain concrete (Item 1), respectively. Moreover, the cracking resistance ranks Grade I.

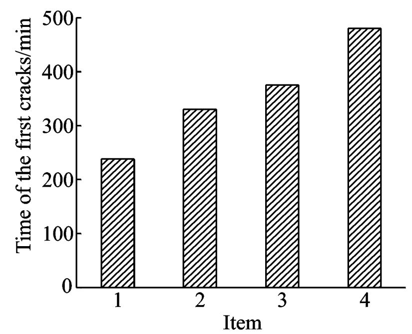

Fig. 2 Time of the first crack in concrete

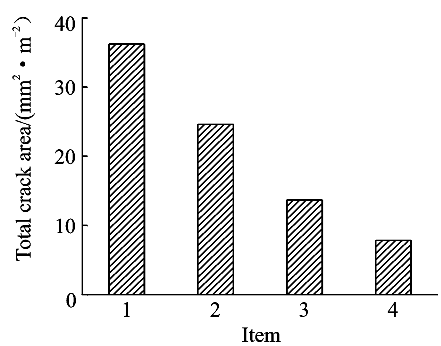

Fig. 3 Total crack area per unit area in concrete

When the content of fiber is increased, the time when the first crack occurs can be delayed obviously, and the numbers of cracks per area and total crack area per area decrease. The results in Figs. 4,5 demonstrate that fiber is quite effective in retarding the first crack as well as reducing the inherent cracking tendency at the early stage of the matrix[15]. Because at this stage the elastic modulus of the fiber is still higher than that of the cementitious matrix.

3.2 Effect of fiber and expansive agent on mechanical properties of concrete pavement

The compressive strengths and impact energies of concrete pavement with fiber and expansive agent are shown in Figs. 6,7. Compared with plain concrete, the 7 d and 28 d compressive strengths of concrete with 1.34% or 2.68% of polypropylene fiber are enhanced by 3% and 4%,

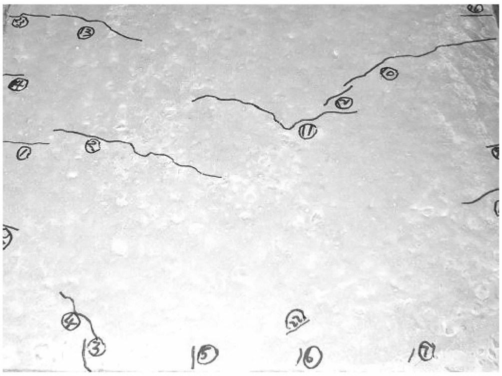

Fig. 4 Cracks of plain concrete

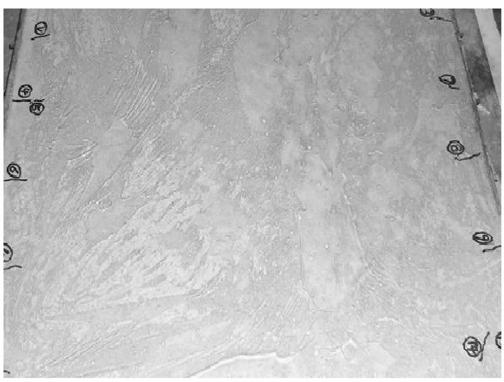

Fig. 5 Cracks of concrete with fiber

or 4% and 2%, as shown in Fig. 6. When the concrete is blended with 2.68 kg/m^3 polypropylene fiber and 20.1 kg/m^3 expansive agent (Item 4), the 7 d and 28 d compressive strengths of concrete are enhanced by 3.2% and 7.5% compared with plain concrete. The results indicate that the effect of polypropylene fiber and expansive agent on the compressive strength of concrete is inapparent.

According to the index of impact toughness W of concrete, the impact energies of concrete are 1 412 W/J, 3 248 W/J, 4 945 W/J and 4 992 W/J, and the impact resistance performance of fiber concrete are enhanced by 130%, 250% and 254% respectively, as shown in Fig. 7. The impact resistance of concrete is improved markedly when the polypropylene fiber is introduced. When the concrete is blended with 2.68 kg/m^3 polypropylene fiber and 20.1 kg/m^3 expansive agent, the impact resistance of concrete is not improved significantly than that of concrete without expansive agent. The result shows that the effect of expansive agent on the impact resistance of concrete is inapparent.

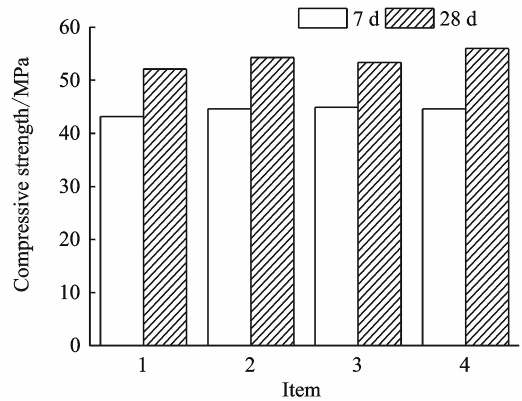

Fig. 6 Compressive strength of concrete

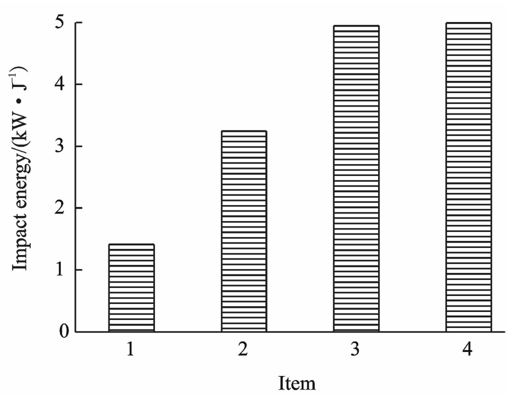

Fig. 7 Impact energies of concrete

3.3 Morphology of concrete with fiber and expansive agent

The SEM images of concrete with 2.68 kg/m^3 fiber, and 2.68 kg/m^3 fiber and 20.1 kg/m^3 expansive agent are shown in Figs. 8, 9.

Since the fiber has good hydrophilicity and strong bonding with cementitious materials, when it is introduced into concrete pavement, the consistency of concrete increases and it can form net structure in plastic concrete[16]. When the heavier particles in the cementitious materials go down, the network structure can take effect of drag. The fibers distributed in the concrete restrain the flowing of concrete and restrict the movement of coarse aggregate. Therefore, the shrinkage of concrete pavement can be reduced and the impact resistance can be improved.

The main chemical composition of the expan-

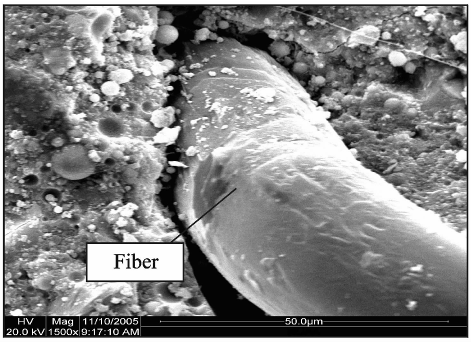

Fig. 8 Morphology of concrete with fiber

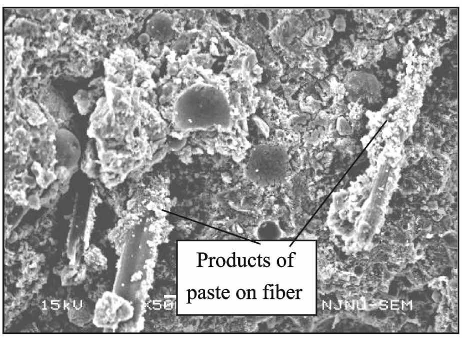

Fig. 9 Morphology of concrete with fiber and EA

sive agent is CaO and MgO. CaO may offset the early shrinkage and provide $Ca(OH)_2$ to react with fly ash in concrete. A later expansive stress caused by MgO can improve the microstructure of concrete and compensate the shrinkage (Fig. 9). Using the expansive agent in concrete can produce expansive stress to compensate the temperature and autogenous shrinkage, and reduce the crack of concrete.

4 Conclusions

The results of this study indicate that the effect of fiber and expansive on the performance of concrete includes the following aspects.

Polypropylene fiber used in conerete can reduce surface cracks, decrease the shrinkage deformation of concrete pavement, and improve the impact resistance performance of concrete pavement, However, for the compressive strength, the effect is slight.

Expansive agent can compensate the shrinkage of concrete, and reduce the cracks of concrete pavement markedly. However, for the compressive strength and impact resistance, the effect is little.

When the fiber and expansive agent are introduced into concrete in an appropriate proportion, they can bring high bonding force with cementitious materials, form an even linkage system and bring an effective reinforced effect and reduce the cracking.

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